Four decades of hindsight into a complex hydropower system

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José P. Matos[1], Pedro Manso[1], Bettina Schaefli[2], Benno Schwegler[3], Andres Fankhauser[3], Martin Seiler[3] and Anton J. Schleiss[1]

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0 Goal

Explore ways to identify and quantitatively describe the modes of operation that take place in a complex hydropower system across several decades (1980 – 2014).

1 The KWO system, in Switzerland

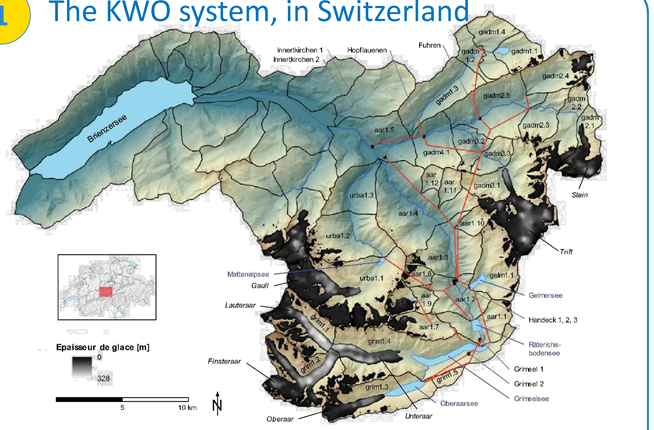

Fig 1. The KWO system and estimated glacier cover in 1993 [1, 2].

- **The *Kraftwerke Oberhasli AG* (KWO) hydropower system (Fig. 1):**
  a) 10 power plants,
  b) 29 turbines,
  c) 1368 MW.
  d) 4 main reservoirs.

2 Data

A wealth of data was used:

- Daily series of all **water fluxes** in the system (since 1980).
- Daily series of **reservoir levels** (since 1980).
- Hourly series of **SPOT market prices** (since 2008).

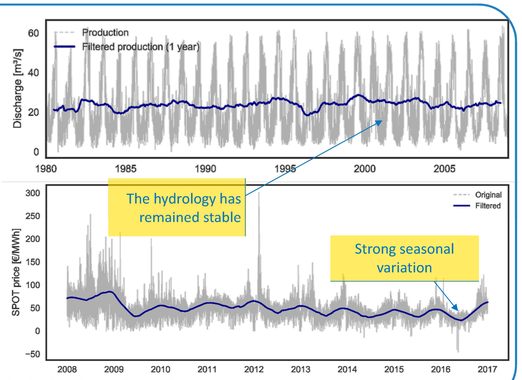

Fig 2. Outflows from the system (a) and SPOT energy prices (b).

3 Visualization

Sankey plots provide an appealing way of visualizing and interpreting system operation states.

- The width of each arrow is proportional to the magnitude of the flux (in this case discharge).
- These plots can be produced automatically, enabling a practical view of the system.

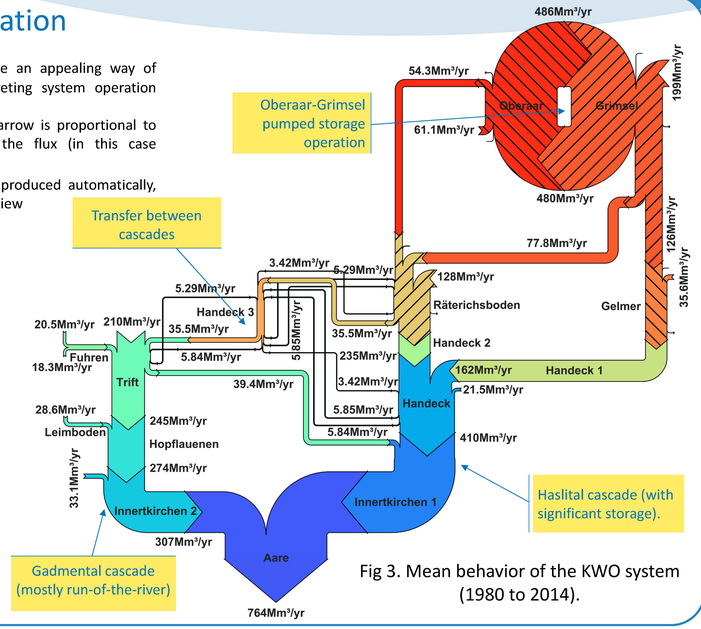

Fig 3. Mean behavior of the KWO system (1980 to 2014).

4 Clustering techniques

How to **reduce the dimensionality** of the dataset so that it can be interpreted ?

- **It depends** on the question being addressed.

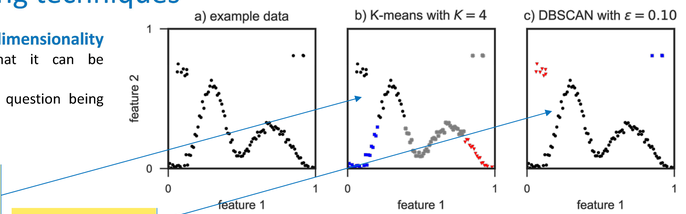

Fig 4. Illustration of how two clustering algorithms operate.

5 Seasonal operations

Seasonal clusters of daily operations can be found using the K-means algorithm.

Significant changes since the 1980's (pumped storage).

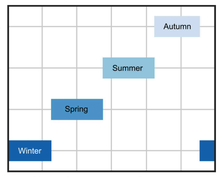

Fig 5. Seasonal clustering (K-means).

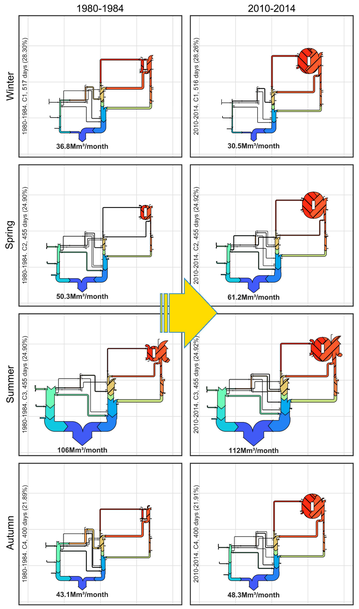

Fig 6. Evolution of seasonal operations (5-year averages).

6 Outlier operation modes

Using DBSCAN clustering one can quickly identify rare operation modes.

- All production through the Gadmental
- Run-of-the-river production
- Filling of the Grimsel reservoir
- Absorbing energy from the system through pumping

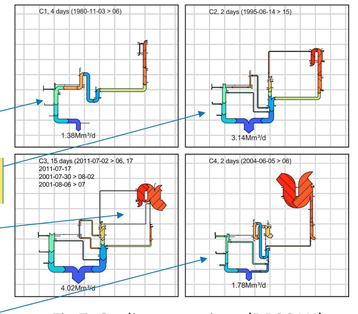

Fig 7. Outlier operations (DBSCAN).

7 Conclusions

- Sankey plots are effective tools to visualize the operation of complex hydropower systems.
- Clustering can be used to reduce the dimensionality and facilitate the interpretation of the operations of a complex hydropower system.
- KWO has undergone significant changes in its operation that can mostly be explained by energy market conditions (stable hydrology on average terms).

8 References and acknowledgements

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(1) Laboratory of Hydraulic Constructions, École Polytechnique Fédérale de Lausanne, Switzerland. pedro.manso@epfl.ch
(2) Faculty of Geosciences and Environment, University of Lausanne, Switzerland.
(3) Kraftwerke Oberhasli AG, Innertkirchen, Switzerland.

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